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Lawrence Livermore National Security, LLC, Livermore, California 94551

LLNL-AR-416970

Treatability Study Summary and Proposed Cleanup Alternatives for the TFA West Area Lawrence Livermore National Laboratory Livermore Site

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September 2009

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Environmental Restoration Department

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1. Introduction

From January 2007 to January 2008, the Environmental Restoration Department (ERD) at the Lawrence Livermore National Laboratory (LLNL) Livermore Site conducted a treatability test in which ground water containing volatile organic compounds (VOCs), primarily perchloroethylene (PCE) was extracted from offsite monitor well W-404, located west of the existing Treatment Facility A (TFA) extraction well field infrastructure (Figure 1). The ground water was filtered and discharged into the sanitary sewer for treatment at the Livermore Water Reclamation Plant (LWRP). The test was conducted to determine whether full hydraulic capture of the contaminant plume could be achieved through pumping at this location, and to evaluate the resulting reduction in PCE ground water concentrations.

Since this treatment technology differed significantly from the remedy proposed in the LLNL Livermore Site Record of Decision (Department of Energy, 1992), the treatability test was publically noticed through an Explanation of Significant Differences (ESD) (Berg et al., 2007). Although PCE concentrations dropped significantly during the test and effective hydraulic capture was achieved, concerns were expressed by the U.S. Environmental Protection Agency (US EPA) regarding the efficacy of VOC treatment by the LWRP, and whether this was an acceptable alternative to ground water treatment by LLNL remedial infrastructure. Accordingly, it was decided to discontinue the treatability test at the end of the first year and not to proceed with implementation of this alternative treatment technology.

Subsequent to the treatability test, a rebound test was conducted to help determine the impact of the year-long test on ground water concentrations in the TFA West area. In addition, different cleanup alternatives to address the ground water contamination in the TFA West area were evaluated. This report summarizes the treatability test and the rebound test, and presents treatment alternatives for the well W-404 area. Submittal of this report meets a September 30, 2009 Federal Facilities Agreement (FFA) milestone listed in Table 5 of the Remedial Action Implementation Plan as amended and approved by the Livermore Site Environmental Restoration Remedial Project Managers from the U.S. Department of Energy, the US EPA, the California Department of Toxic Substances Control, and the Regional Water Quality Control Board, San Francisco Bay Region in the March 2009 Consensus Statement.

2. Treatability Test

Treatment Facility A (TFA) and its extraction wells, located in the southwest corner of the Livermore Site (Figure 1) were designed to hydraulically control and remediate the western and southwestern onsite and offsite plumes, including the ground water contamination at well W-404. This well is the westernmost known extent of PCE above its 5 parts per billion (ppb) maximum contaminant level (MCL) in hydrostratigraphic unit 2 (HSU 2). All other VOCs in well W-404 area ground water, including 1,1-DCE, TCE, 1,2-DCE, and chlororform, are below their respective MCLs. TFA and its associated wellfield began operating in September 1989 and have remediated much of the HSU 2 offsite plume while stopping further downgradient migration of the plume in the vicinity of well W-404. Offsite PCE concentrations have declined from over 200 ppb in 1989 to below 25 ppb in 2009. However, in the 1990s, the ground water plume around well W-404 was determined to be in a hydraulic stagnation zone (i.e., immediately down gradient of a ground water capture zone, in an area where ground water flow is negligible due to the induced flat ground water gradient there) (Figure 2) creating a detached portion of the VOC plume that was not being remediated. PCE concentrations at well W-404 have been stable, averaging about 22 ppb between 1991 and 2006.

These data suggest that without active remediation, the well W-404 area stagnation zone could continue to exist for decades (assuming the TFA offsite extraction wellfield to the east continued to operate), and the VOC concentrations would decline only through natural attenuation due to dispersion, dilution, and adsorption.

To address cleanup of the well W-404 area, also known as the TFA West area, a year-long treatability study was conducted with regulatory agency concurrence (Berg et al., 2007). The objectives of the test were to:

- evaluate whether ground water extraction at well W-404 would effectively hydraulically capture the TFA West contaminant plume,
- determine whether ground water extraction at well W-404 would result in a permanent reduction in VOC concentrations at this location, and
- evaluate whether treatment of the VOCs by the LWRP rather than an LLNL ground water treatment unit would be an acceptable remedy for cleaning up the TFA West plume in a cost-effective and relatively rapid manner.

During the treatability test, ground water extracted from well W-404 flowed in a pipeline to TFA West. This facility included a particulate filter, pressure gauges, flow measurement, sampling port, and controls. The extracted, filtered ground water was then discharged to the City of Livermore's sanitary sewer for treatment at the LWRP.

2.1. Hydrogeologic Analyses

A data collection and analysis plan was developed to identify an optimal flow rate for operating well W-404 to achieve hydraulic capture and cleanup of the TFA West area, and to evaluate whether the TFA-West treatability test met its objectives. An extraction well-field start-up work plan was developed and implemented for operating the treatment facility and for collecting hydraulic and chemical data. Subsequently, a hydrogeologic analysis was performed using the collected data and the current conceptual model of the area. A well hydraulics and capture zone analysis was performed using the first three months of data from the treatability test to determine the optimal well W-404 flow rate. Ground water VOC data collected prior to and during the test were analyzed to evaluate the effectiveness of this treatment alternative in reducing concentrations in the area.

2.2. Work Plan and Data Collection

In November 2006, an extraction well-field start-up work plan describing the operation of TFA-West during a step flow rate test was completed. A three-month-long step flow rate test was begun in February 2007 to evaluate capture zones under different flow rates and to quantify well efficiency and sustainable yield. The well W-404 extraction flow rates for each step were determined based on available drawdown and consisted of 25 gallons per minute (gpm), 38 gpm, and 43 gpm. During the test, continuous water level and flow rate data from well W-404 were collected by the TFA-West data acquisition system (DAS). Two observation wells (W-120 and W-1701) located upgradient (to the east) of well W-404 (Figure 2) were instrumented with water level transducers and data loggers to continuously record water level data. Additionally, monthly water levels were measured in all surrounding TFA HSU 2 monitor wells to define the HSU 2 potentiometric surface in the TFA area for the three different flow rates of the step test. To evaluate changes in VOC concentrations during the test, ground water samples from well W-404 were collected for VOC analysis on the first, third, and seventh day of pumping, then once a week for the first month, monthly for the first quarter, and quarterly thereafter for the duration of the treatability study.

2.3. Well Hydraulics Data Analysis

The well hydraulics analyses performed on extraction well W-404 included:

- water level response of the two observation wells,
- hydraulic test analysis of extraction and observation well continuous flow rate and water level data, and
- well efficiency analysis using the three step flow rate data.

During each flow rate step, a significant water level response was observed in both wells W-120 and W-1701, given the 300 to 400 foot distance between the pumping and observation wells. Over the three flow rate steps, a range of one to four feet of drawdown was recorded in the observation wells. This response indicates good hydraulic communication between the pumping and observation wells.

Using the hydraulic test analysis software AQTESOLV, the HSU 2 hydraulic conductivity within the vicinity of W-404 was calculated. The calculations were performed using both the pumping well continuous flow rate and water level data, and the observation well continuous water level data. The calculated hydraulic conductivity for these data range from 285 to 552 ft^2/day. These results, along with the good hydraulic response in the observation wells, indicate that a confined homogenous isotropic aquifer is a reasonable conceptual model for evaluating the HSU 2 ground water system in the TFA-West area. The well W-404 hydraulic conductivities are similar to those from other wells in the TFA-West area, and the results were used in the subsequent capture zone analysis.

2.4. Capture Zone Analysis

Water levels in HSU 2 monitor and extraction wells in the TFA area were measured contemporaneously during each of the three flow rate steps. These data were contoured to produce three maps of the steady-state potentiometric surface. From the potentiometric surfaces, capture zones that honor the field conditions were interpreted for well W-404 for each of the flow rate step to determine optimal capture. The potentiometric surface and estimated capture zone for the final April 2007 flow rate step of 43 gpm is shown on Figure 3. The observation data, potentiometric surfaces, and calculated hydraulic conductivities were then used as calibration data for the development of an analytical element model of HSU 2 in the TFA area using the WINFLOW software package. Reverse particle tracking was implemented in the model to simulate capture zone geometry under various pumping scenarios and worst-case conditions. The worst-case conditions that were simulated were increased agricultural pumping in close proximity to the TFA West area. This is an important consideration given the potential for the Wente Winery to implement agricultural pumping at wells located on the south side of East Avenue. Results of this capture zone analysis suggested that a continuous pumping rate of at least 32 gpm from well W-404 would meet the treatability test objective.

Accordingly, for the subsequent nine months of the test from April 2007 to January 2008, well W-404 was pumped at flow rates exceeding the identified minimum flow rate of 32 gpm. Figure 3 shows the HSU 2 ground water elevation contour map for April 2007. The estimated hydraulic capture area fully contains the extent of the well W-404 detached plume and is consistent with the simulated capture zone analysis discussed above.

2.5. Mass Removal and Concentration Trends

Between January 2007 and January 2008, about 19.0 million gallons of ground water were extracted from well W-404. As shown on Figure 4, PCE concentrations in well W-404 rapidly declined from about 19 ppb at the start of the test (May 2006) to about 7 ppb in July 2007, where concentration levels remained until the end of the test (January 2008). During the year-long treatability test, an estimated 0.9 kilograms of VOCs were removed from ground water.

Although PCE concentrations appeared to decline rapidly between January and July 2007, whether this represented an actual decrease in the TFA West area contaminant plume concentrations due to pumping could not be resolved based on the data collected during the test. Since the monitor wells adjacent to well W-404 contain much lower levels of PCE (Figure 5), at least some portion of the decline is likely due to dilution as cleaner water was drawn into the well screen from areas to the east, south, and probably north. In addition, well W-404 is screened such that it captures the entire thickness of HSU 2. Accordingly, because only a portion of HSU 2 contains PCE, vertical dilution by cleaner water is also thought to occur in well W-404.

2.6. Test Termination and Post-Test TFA Flow Optimization

At the request of the US EPA, the treatability test was terminated on January 14, 2008. Following the test, a hydrogeologic analysis was conducted to ensure that the TFA West PCE ground water plume would once again be immobilized within the stagnation zone downgradient from the TFA remedial well field hydraulic capture area. Accordingly, the calibrated WINFLOW ground water flow model was used to simulate ground water extraction and resulting capture zones along the TFA Arroyo Seco pipeline (Figure 6). Modeling was performed to define the optimal pumping rates needed to maintain hydraulic containment of the TFA HSU 2 plume and to ensure that the TFA West plume would continue to reside within the stagnation zone. The model indicated optimal flow rates for wells W-109, W-457, W-903, and W-904 of 36 gpm, 10 gpm, 30 gpm, and 20 gpm, respectively. Once the treatablity test had ended, these optimal flow rates were implemented. During first quarter 2008, water level data were collected monthly in TFA ground water extraction and monitoring wells. Based on the potentiometric surfaces developed from these data, capture zones that honor the field conditions were constructed. The Second Quarter 2009 HSU 2 TFA ground water elevation contour map with the PCE ground water plume superimposed is shown on Figure 5. As indicated in Figure 5, the TFA West ground water plume is once again within the stagnation zone downgradient from the TFA Arroyo Seco remedial wellfield.

3. Rebound Test

To help determine the amount of concentration decline that actually occurred in the TFA West area as a result of the treatability test, a rebound test was conducted following the shutdown of TFA West. Once ambient conditions were re-established in the area, VOC concentrations would likely be more representative of actual plume concentrations. Accordingly, fifteen monthly ground water samples were collected from well W-404 for VOC analysis between February 2008 and May 2009.

As shown on Figure 4, PCE concentrations rebounded slowly at well W-404, from about 7 ppb to around 11 ppb over this time interval. Based on the fact that PCE concentrations were around 19 ppb prior to the start of the test, it appears that concentrations in the TFA West PCE ground water plume have been reduced by about forty per cent (from 19 to about 11 ppb) due to ground water extraction during the treatability test. The current concentrations in the TFA West area are shown on Figure 5. The rate of decline and rebound in the TFA West area suggest that cleanup to concentrations below the 5 ppb PCE MCL will likely take considerably longer than the two years described in the ESD (Berg et al., 2007), possibly on the order of 15 years. The 15-year cleanup time estimate is based on a simple mixed-tank model and is considered to be a very conservative estimate.

4. Treatment Alternatives

In response to a request from stakeholders to provide alternative remedies for the VOCs in ground water in the TFA West area, this section presents an analysis of remediation technologies that could achieve the remedial action objectives (RAOs) for the detached portion of the VOC plume in the vicinity of well W-404. The hydrogeologic and capture zone analyses and revised time-to-cleanup estimate determined during the treatability and rebound tests provided a sound basis for developing and evaluating a list of potential treatment options. Additionally, a broad range of treatment options was identified based on potential effectiveness of treating the VOC plume. The treatment options were then screened based on their relative advantages and disadvantages. The screening analysis yielded four treatment alternatives for which concept level designs and costs were developed. Comparison criteria from US EPA were then applied to each of the four alternatives to identify the most appropriate and effective alternative.

4.1. Identification and Screening of Treatment Technologies

The goal of well W-404 ground water treatment is to achieve RAOs in a safe and cost effective manner while minimizing short and long term impacts to the community in which well W-404 is located. To meet this goal, ERD identified nine technologies with the potential to achieve RAOs. These technologies include in-well treatment, ground water extraction and *ex situ* treatment both at well W-404 and at TFA, and maintaining hydraulic control while treating ground water *in situ*. Each of these technologies was screened based on their likely effectiveness to remediate the low concentrations of VOCs near well W-404, and then were compared based on their relative advantages and disadvantages.

Table 1 summarizes the screening analysis for the following general technologies:

- In-well air stripping with vapor-side treatment;
- Ground water extraction and *ex situ* treatment via:
    - air stripping at W-404 or at TFA,
    - granular activated carbon (GAC) at well W-404,
    - chemical oxidation using ultraviolet light (UV-oxidation), or
    - abiotic reductive dehalogenation; and
- *In situ* treatment in the well W-404 area by:
    - chemical oxidation;
    - abiotic reductive dechlorination; or
    - *in situ* biostimulation while continuing to pump at upgradient well W-109.

In situ chemical oxidation technologies were rejected due to safety considerations associated with handling and using the chemical oxidants, the high flow conditions in the area, and the uncertainty associated with achieving complete hydraulic control of the target treatment zone. Biostimulation technologies were rejected because they would not likely be effective due to the relatively low VOC concentrations and the predominance of highly oxygenated aquifer conditions. Biostimulation requires the presence of microorganisms that live in anaerobic conditions. The dissolved oxygen content in ground water at well W-404 is greater than 4 milligrams per liter (mg/L), which suggests aerobic conditions. Hence, anaerobic microorganisms are not likely to be present.

While in-well air stripping and ground water extraction and treatment with air stripping at well W-404 are potentially effective, these technologies were rejected because of noise and air discharge concerns in the residential subdivision where well W-404 is located. Ground water extraction and treatment by UV-oxidation was rejected for similar reasons and due to its use of hazardous materials, high energy consumption, and ERD experience with scale buildup on UV light chambers that created operation and maintenance problems.

4.2. Summary of Treatment Alternatives

Four treatment alternatives were retained for further analysis. These include:

- ground water extraction and *ex situ* treatment at TFA (Alternative 1),
- ground water extraction and *ex situ* treatment proximal to well W-404 using GAC (Alternative 2),
- ground water extraction and *ex situ* treatment proximal to well W-404 using abiotic reductive dechlorination (Alternative 3), and

- *in situ* treatment by abiotic reductive dehalogenation (Alternative 4).

Table 2 presents concept-level designs for each of the four alternatives. Figure 6 shows the location and rough layout of each alternative.

Alternative 1 consists of plumbing improvements to connect well W-404 to the Arroyo Pipeline for treatment at TFA. Ground water from well W-404 would be treated by the existing air-stripping and vapor-phase GAC system at TFA. This alternative includes installation of up to 1,300 feet (ft) of new, double-walled, underground pipeline beneath the public footpath on the south side of Arroyo Seco (Alternative 1a), or in the public right of way beneath Charlotte Way and Susan Lane (Alternative 1b). Estimated Alternative 1 costs are $560,000 to construct and operate annually for 15 years.

Alternative 2 is ground water extraction from well W-404, and installation and operation of a GAC and ion exchange system near well W-404 to treat the ground water and discharge it to Arroyo Seco. This alternative includes construction of a 13-ft wide x 16-ft long x 10-ft high security and sound attenuation enclosure in Big Trees Park to contain two 2,000 pound (lb) GAC units and two in-series ion-exchange columns. Treated water would be discharged to the underground storm drain along Charlotte Way or directly to Arroyo Seco. Estimated Alternative 2 costs are $1,100,000 to construct and operate annually for 15 years.

Alternative 3 is ground water extraction from well W-404, installation and operation of an aboveground sulfur modified iron (SMI) system to the treat ground water, and discharge of treated ground water to Arroyo Seco. This alternative includes construction a 15-ft wide x 20-ft long x 14-ft high security and sound attenuation enclosure in Big Trees Park to contain a 30,000-lb SMI reactor vessel. Estimated Alternative 3 costs are $3,100,000 to construct and operate annually for 15 years.

Alternative 4 is injection of zero valent iron (ZVI) slurry into HSU 2 to provide abiotic reductive dechlorination of VOCs in ground water. This alternative includes installation of 17 injection boreholes on a 15 ft grid to inject 72,000 lbs of atomized ZVI slurry into HSU 2 approximately 150 to 160 ft below ground surface. Estimated Alternative 4 costs are $1,300,000 to construct and operate annually for 15 years.

The estimated treatment alternative costs, including capital cost, annual cost, and 15-yr present value life cycle cost, are presented in the table below.

Table 3. Estimated treatment alternative costs.

Treatment Alternative	Capital Cost	Annual Cost	15-yr Present Value Life Cycle Cost
Pipeline Extension	$480,000	$8,000	$560,000
GAC and Ion Exchange Treatment System	$510,000	$57,000	$1,100,000
Sulfur Modified Iron Treatment System	$720,000	$230,000	$3,100,000
Zero Valent Iron Slurry Injection	$1,250,000	$4,000	$1,300,000

4.3. Evaluation of Treatment Alternatives

Table 4 summarizes the analysis of treatment alternatives for well W-404 area ground water. The four alternatives were analyzed against US EPA threshold, primary balancing, and modifying criteria identified in the National Oil and Hazardous Substance Pollution Contingency Plan (NCP) 40 CFR Section 300.430(e)(9)(iii). While these criteria are not directly applicable to this evaluation, they do provide a useful framework for comparing treatment alternatives.

4.3.1. Description of Comparison Criteria

According to US EPA, threshold criteria must be met for an alternative to be considered further. The threshold criteria include protection of human health and the environment and compliance with federal and state applicable or relevant and appropriate requirements (ARARs).

Primary balancing criteria help distinguish among alternatives that meet the threshold criteria. They include short- and long-term effectiveness, reduction in contaminant toxicity, mobility and volume (TMV), and implementability. The long-term effectiveness criteria consider the adequacy and reliability of remedial controls and the magnitude of residual risk after the alternative is implemented. The TMV criteria consider whether an alternative destroys toxic contaminants, reduces contaminant mobility, reduces the total mass of toxic contaminants, and reduces the total volume of contaminated media. The short-term effectiveness criteria consider exposure of the community to health risks during implementation, exposure of workers during construction, environmental impacts, and time to achieve remedial objectives. The implementibility criteria consider the ability to apply the technology, reliability of the technology, monitoring considerations, availability of equipment and any specialists, and the ability to obtain approvals from regulatory agencies. Estimated costs include capital, operating and present value life-cycle cost.

Modifying criteria include state and community acceptance. Federal and State acceptance will be based upon RPM regulatory review and community acceptance will be evaluated during upcoming Technical Advisory Grant (TAG) and Community meetings.

4.3.2. Comparison of Alternatives

If properly constructed and maintained, all four alternatives would protect human health and the environment. Alternatives 1 and 2 have the highest certainty of overall protection of human health and the environment since they are both proven technologies and used by LLNL. In addition, Alternatives 1 and 2 are within the treatment framework envisioned in the ROD and would comply with ARARs. Alternative 4 is for *in situ* remediation which is a technology not considered in the ROD. An Explanation of Significant Differences (ESD) may be required to implement Alternative 4.

All four alternatives will reduce the residual risk from VOCs in ground water. Alternatives 1 and 2 are proven, reliable remediation alternatives. Alternatives 3 and 4 are newer innovative technologies and, as such, there is some uncertainty about their effectiveness. The completion of bench- and field-scale testing would be required to reduce this uncertainty. LLNL monitoring and other management controls would be used to confirm effectiveness.

Alternatives 1 and 2 reduce TMV by transferring VOCs in extracted ground water to a treatment medium which is then disposed or recycled. Alternative 3 reduces TMV by reducing VOCs in extracted ground water to chloride ions and innocuous by-products. If effective, Alternative 4 would also reduce TMV by reducing VOCs to chloride ions and innocuous by-products, except the reduction would occur *in-situ*.

All four alternatives are expected to achieve RAOs within a reasonable time period, currently thought to be on the order of 15 years (see Section 3) for Alternatives 1 through 3, and shorter for Alternative 4. Exposure of construction workers and the community to VOCs during construction and impacts to the environment are expected to be minimal for all alternatives. Alternatives 1 and 4 would involve short-term disruption to the local community but no long term visible structure would be built. Drilling activities associated with Alternative 4 would be noisy in the short term and cause significantly more disruption than the underground pipeline installation associated with Alternative 1. Alternatives 2 and 3 would require construction of a permanent (15 year duration) treatment compound in Big Trees Park.

Alternatives 1, 2 and 4 are all implementable using readily available construction materials and techniques, and can be permitted by the appropriate regulatory agencies. Uncertainty associated with the effectiveness, supply and long-term availability of the SMI in Alternative 3 raises questions about its implementability. Alternatives 2 and 3 require acquisition of land in Big Trees Park. Alternative 1 is the most readily implementable because work is done in the public right-of-way using common utility installation techniques. However, extensive consultation with and approval by the City of Livermore would be required for implementation of Alternative 1. Existing structures may limit effective application of ZVI in Alternative 4.

Given a 15-year operational period, the estimated cost for Alternative 1 is substantially lower than the other alternatives. Capital, operation and present value life cycle costs (PVLCC) are lowest for Alternative 1. Capital costs associated with Alternative 2 are comparable to Alternative 1, however operational costs area substantially higher. The estimated cost associated with Alternative 3 is the highest overall due to uncertainty of the consumption rate of SMI when compared to other treatment media. Capital costs associated with Alternative 4 are highest overall, but if successful, operation costs are the lowest of all four alternatives.

Finally, the four alternatives were also compared based on a preliminary review of the National Environmental Policy Act (NEPA) compliance. As detailed in Table 4, the impact categories considered included land use, ecology, water use and quality, air quality, waste, and aesthetics. This initial analysis, conducted by LLNL Environmental Protection Department (EPD) staff, suggests that Alternative 1 has the least NEPA impact of the four alternatives considered.

The analysis summarized in this report shows that Alternative 1 appears to offer the best balance of the threshold and primary balancing criteria.

5. Summary

A year-long treatability test was conducted from 2007 to 2008 to evaluate the effectiveness of ground water extraction and an alternative remedy for cleanup of the detached portion of the HSU 2 plume in the vicinity of offsite well W-404. The treatability test was terminated on

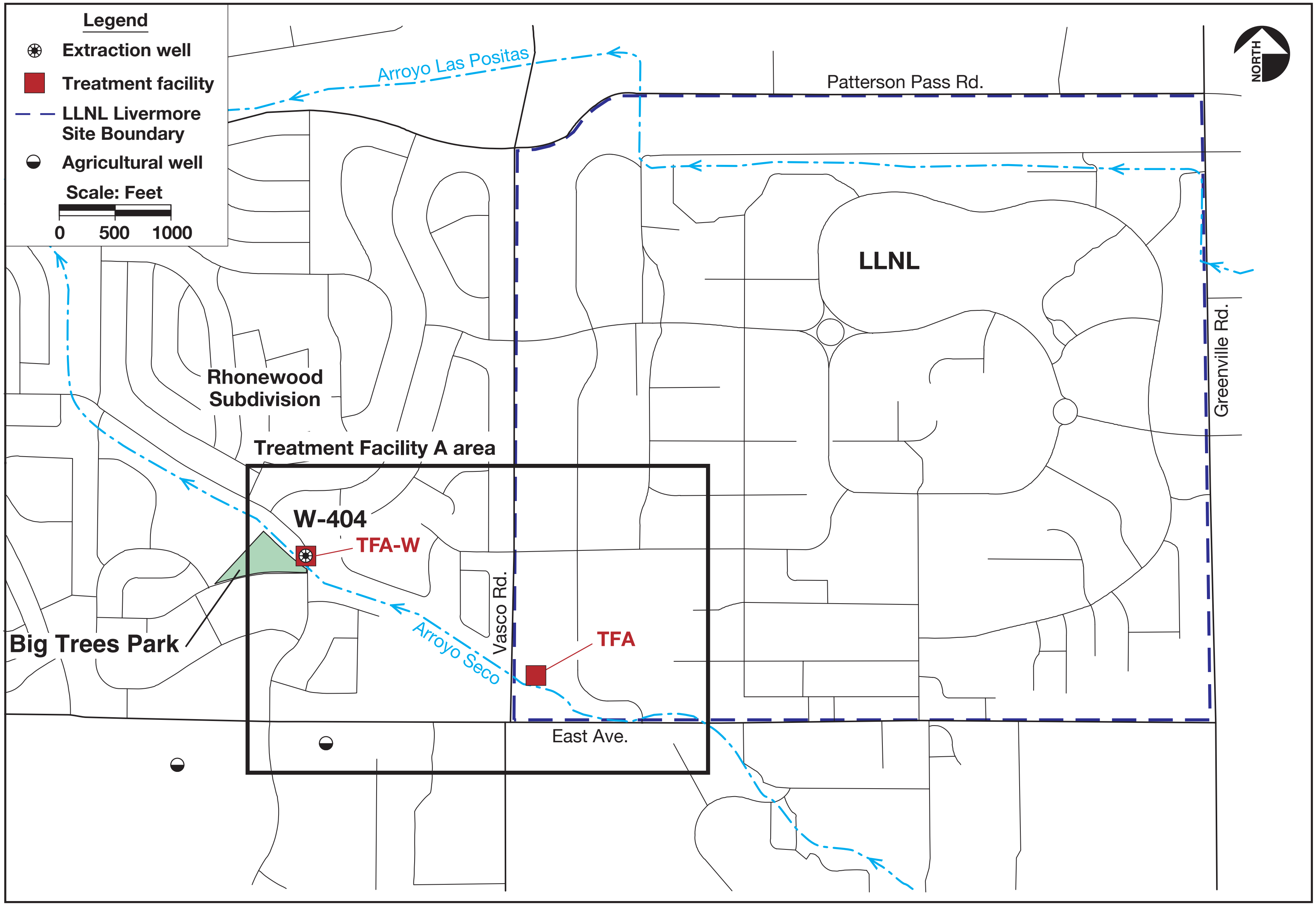
January 14, 2008. Analytical results from a rebound test show that PCE concentrations in the TFA West area plume appear to have decreased by about 40%, from about 19 ppb to about 11 ppb, as a result of ground water extraction during the treatability test. A hydrogeologic analysis of treatability and rebound test results suggest that the well W-404 area plume will take considerably longer than the two years described in the ESD (Berg et al., 2007) to achieve ground water cleanup at this location. These findings were used as a basis for developing long-term cleanup alternatives for the TFA West area.

Four other treatment alternatives were evaluated for cleanup of VOCs in ground water in the well W-404 area, including a pipeline extension to connect well W-404 to the Arroyo Seco Pipeline (Alternative 1), installation of a GAC and ion-exchange system near well W-404 (Alternative 2), installation of a SMI treatment system near well W-404 (Alternative 3), and *in situ* destruction of VOCs by injection of a ZVI slurry in the well W-404 area (Alternative 4). Alternatives 3 and 4 are newer innovative technologies and, as such, there is some uncertainty about their effectiveness. The completion of bench- and field-scale testing would be required to reduce this uncertainty. In addition, existing structures may limit effective application of ZVI under Alternative 4. Alternatives 2 and 3 require acquisition of land in Big Trees Park for siting new treatment facilities, and therefore may not be acceptable to the City of Livermore and the community. Alternative 1 would most likely require extensive consultation with and approval by the City of Livermore prior to implementation, but offers the best balance of threshold and primary balancing criteria.

6. References

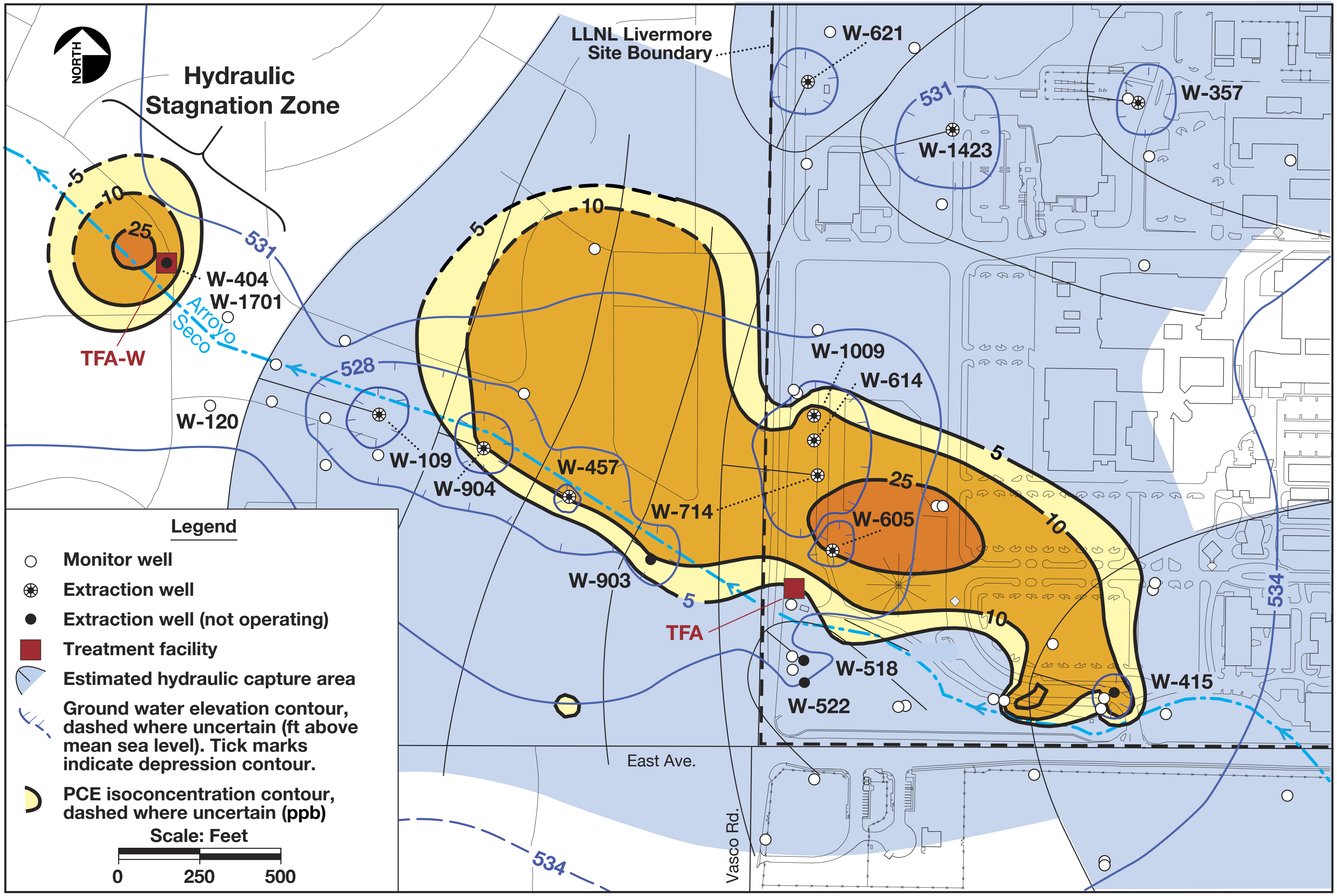
Berg, L. L., R. W. Bainer, S. J. Coleman, Z. Demir, E. N. Folsom, W. A . McConachie, C. M. Noyes, W. S. Sicke, (2007) *Draft Explanation of Significant Differences for Offsite Plume Remediation Near Well W-404, Lawrence Livermore National Laboratory, Livermore Site,* Lawrence Livermore National Laboratory, Livermore, Calif. (UCRL-AR-236120-DRAFT).

Figures



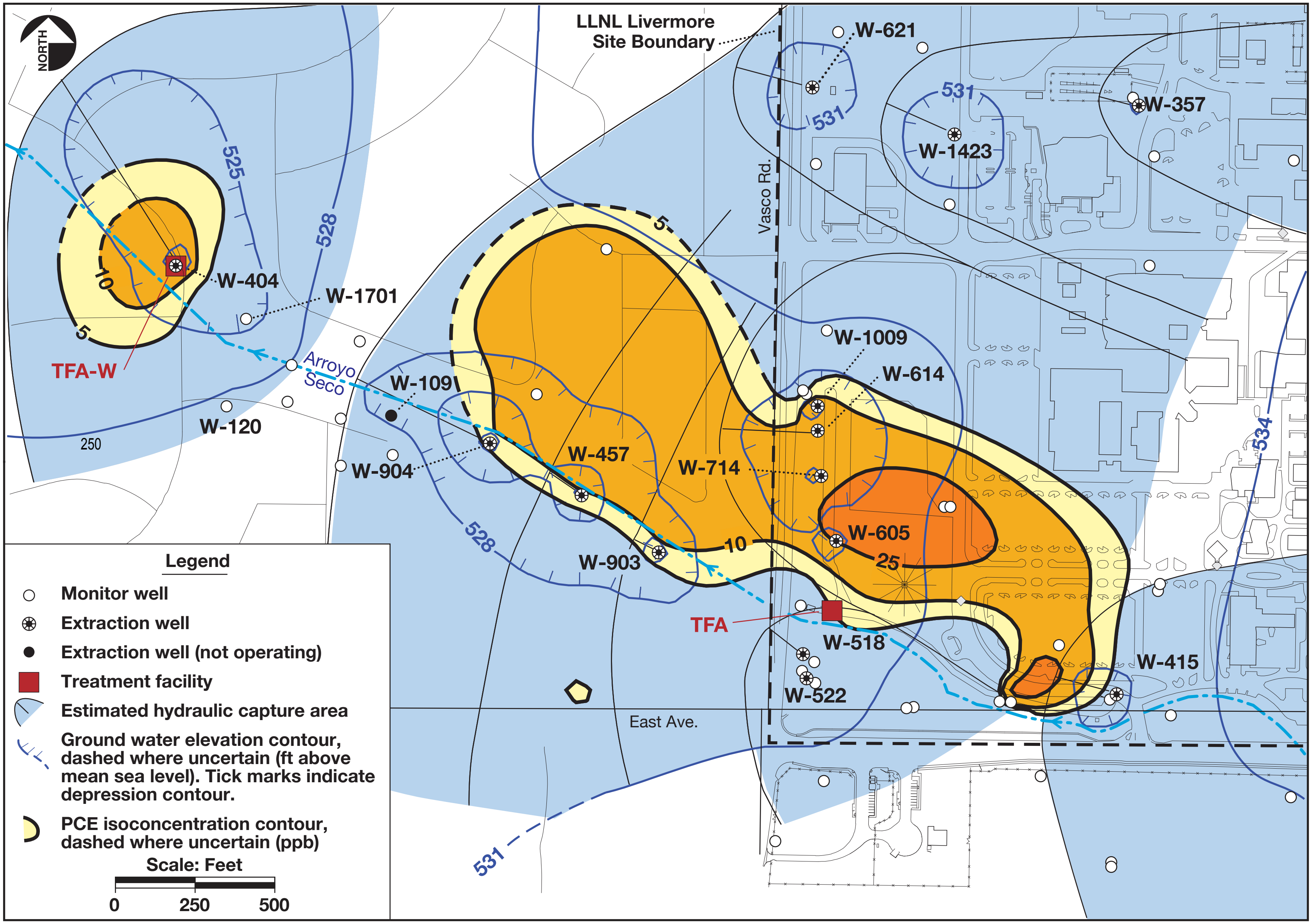
ERD-LSR-09-0003

Figure 1. Location of well W-404, TFA West, and the Treatment Facility A area at and near the LLNL Livermore Site.



ERD-LSR-09-0004

Figure 2. Pre-treatability test map of HSU 2 showing the areal extent of PCE in ground water and the estimated TFA extraction wellfield hydraulic capture area, Second Quarter 2006.



ERD-LSR-09-0005

Figure 3. Treatability test map of HSU 2 showing the areal extent of PCE in ground water and estimated hydraulic capture areas for the well W-404 and the TFA extraction wellfield, Second Quarter 2007.

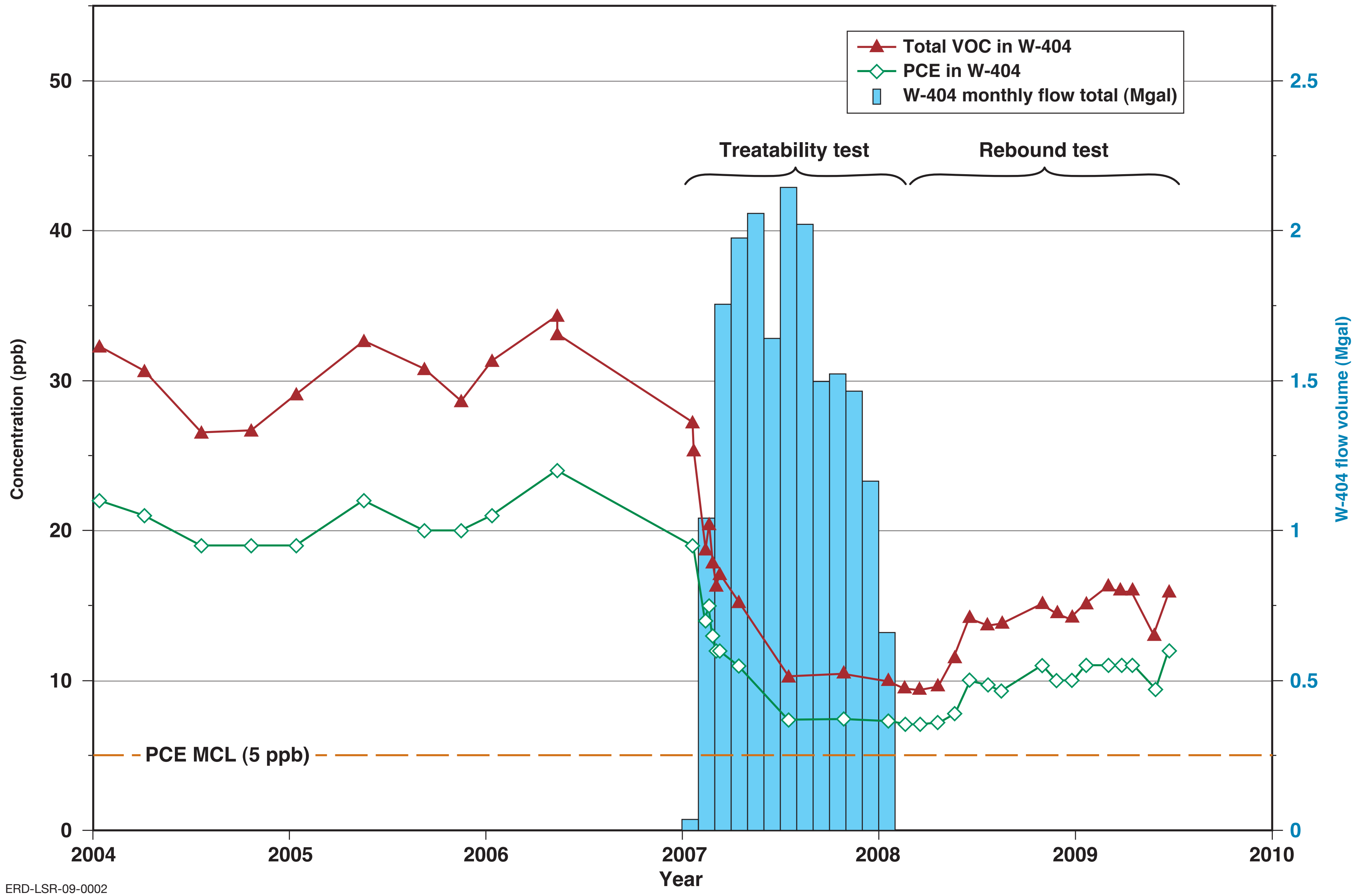
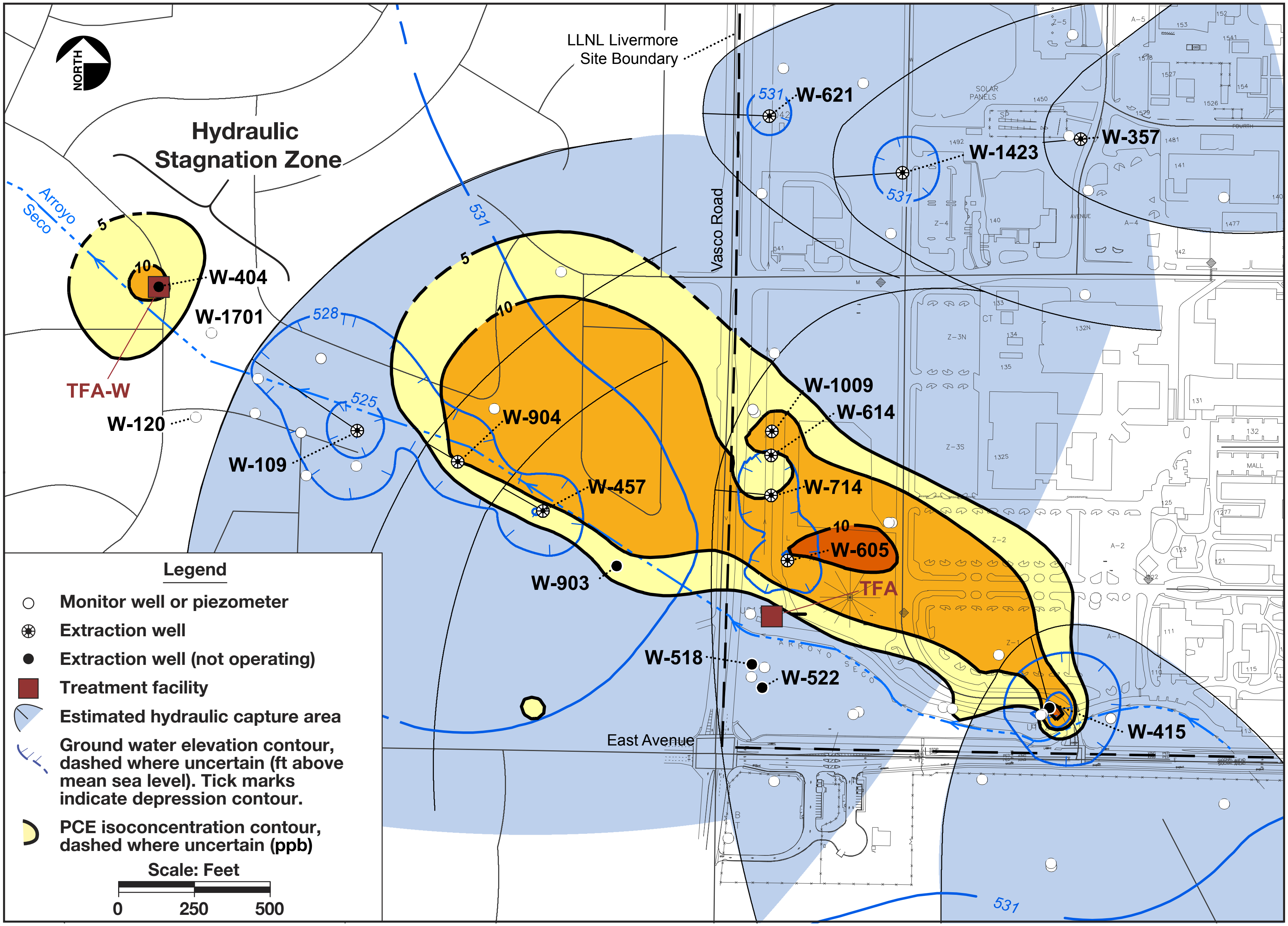
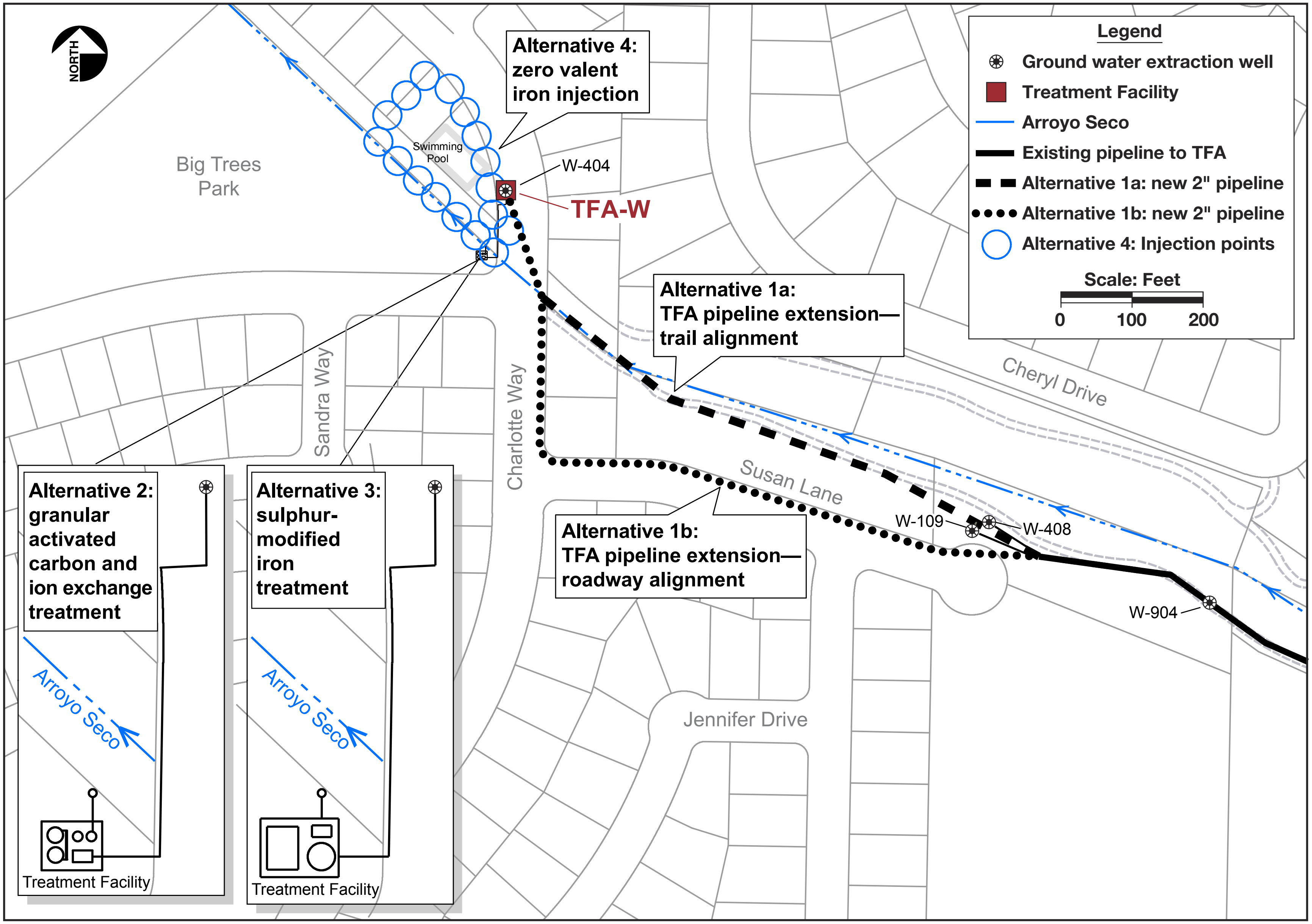


Figure 4. Total VOC and PCE concentrations in well W-404 ground water over time in comparison to volume of extracted ground water.



ERD-LSR-09-0006

Figure 5. Post-treatability test map of HSU 2 showing the areal extent of PCE in ground water and the estimated TFA extraction wellfield hydraulic capture area, Second Quarter 2009.



ERD-LSR-09-0007

Figure 6. Treatment alternatives for ground water at extraction well W-404, west of the LLNL Livermore Site.

Tables

Table 1. Preliminary Treatment Technologies Summary for the TFA West Area, Lawrence Livermore National Laboratory, Livermore, California.

Technology	Description	Effectiveness	Advantages	Disadvantages
Underground Pipeline to TFA	This option involves installation of an underground pipeline to connect well W-404 to the existing Arroyo Pipeline for treatment of volatile organic compounds (VOCs) at Treatment Facility A (TFA). TFA treats ground water using a low-profile air stripper with vapor-phase granulated activated carbon (GAC) treatment.	Effective in remediating VOCs in well W-404 ground water. TFA has ample treatment capacity.	• Proven technology at LLNL. • May be most cost-effective option. • Limited construction and maintenance in well W-404 area.	• Potential access / encroachment issue or utility conflicts. • Reduced flow capacity in Arroyo Pipeline for other wells. • Treatment duration may be 15 years to achieve cleanup goals.
In-well stripping	This technology is a combination of in-well air stripping processes. A typical circulation well consists of two hydraulically separated well screens: a lower screen where compressed air is injected and aerated ground water is drawn into the well, and an upper screen where vapor is withdrawn and treated water is released to the formation. The density gradient between the aerated water and the upper treated water drives flow through the well. The dissolved contaminants are transferred to vapor phase. Contaminated vapors can be removed and treated aboveground by GAC.	Effective in remediating VOCs in well W-404 ground water.	• No water discharge requirements and related permits.	• May require alteration / modification of well W-404. • Blowers / air compressors are noisy. • Requires permit from Bay Area Air Quality Management District (BAAQMD), health risk assessment, and potential public notice. • No hydraulic plume capture / control. • Treatment duration may be 15 years to achieve cleanup goals.
Ex situ liquid phase granular activated carbon (GAC)	GAC is porous and has a large surface area for adsorption of organic compounds. GAC is placed in a column equipped with a system to distribute the ground water containing VOCs evenly over the GAC bed. VOCs are absorbed to the carbon surface as the water passes through the GAC bed. Two to three GAC beds are typically operated in series. With time, the carbon becomes saturated with VOCs and the absorptive capacity of the GAC bed decreases. The spent carbon is then exchanged with new carbon and sent offsite for regeneration or disposal.	GAC is effective for a broad range of organic compounds. Complete removal of VOCs can be achieved irrespective of initial load or flow rates.	• Proven technology at LLNL. • Can remove well W-404 VOCs to non-detectable levels. • Potential to treat ground water from additional wells if needed.	• Requires regular GAC change-out. • Treatment duration may be 15 years to achieve cleanup goals. • Requires construction of a treatment facility in Big Trees Park.
Ex situ air stripping	Air stripping is treatment by contacting the water with a flow of air to transfer dissolved VOCs from the liquid phase to the vapor phase. The most common stripper types are 1) packed column which utilize a packing media within a vertical tower; and, 2) low-profile /sieve tray which uses stacked, perforated trays to allow water to cascade over a countercurrent air flow. To prevent release to the atmosphere, VOCs from the exhaust air stream are commonly adsorbed by GAC.	Effective in remediating VOCs in well W-404 ground water.	• Proven technology at LLNL.	• Blowers are noisy. • Vapor treatment is required. • Requires permit from BAAQMD, health risk assessment, and potential public notice. • Treatment duration may be 15 years achieve cleanup goals.
Ex situ Ultra violet (UV) /chemical oxidation	This process involves the destruction of organic compounds using strong oxidizing agents (hydrogen peroxide (H_2O_2) or ozone (O_3)). The process employs UV light to increase the rate of oxidation, which both creates hydroxyl radicals and breaks bonds in the organic molecules.	LLNL experience suggests relatively high power consumption for PCE in low concentrations similar to those in ground water from well W-404.	• No discernable advantage over GAC for this application.	• High operation and maintenance cost. • Handling of hazardous materials (H_2O_{2x} O_3) and high energy consumption. • Treatment duration may be 15 years to achieve cleanup goals.
In situ oxidation (chemical)	*In situ* chemical oxidation is based on the delivery of chemical oxidants to contaminated media to destroy the contaminants by converting them to innocuous compounds. The oxidant can be delivered to the subsurface though injection or sparging wells. The oxidants applied in this process are typically H_2O_2, potassium permanganate ($KMnO_4$), O_3, or Fenton's Reagent.	Effective in remediating VOCs when geochemistry is well understood and oxidation is practical. May not be effective at well W-404 due to low concentration of PCE.	• If successful, shorter time to achieve remediation goals. • No water discharge.	• Health and safety protection measures are required for oxidant handling. • High intensity, short term disruption in well W-404 area. • Potential to oxidize chromium. • No hydraulic capture / control of plume.

Table 1. Preliminary Treatment Technologies Summary for the TFA West Area, Lawrence Livermore National Laboratory, Livermore, California (continued).

Technology	Description	Effectiveness	Advantages	Disadvantages
In situ reductive dehalogenation (biostimulation)	Biostimulation is a process that involves stimulating indigenous microbial cultures by adding nutrients to encourage reductive dehalogenation. Nutrients commonly injected include edible oils, cheese whey, molasses, sodium lacate, and/ or proprietary nutrients such as HRC (a proprietary polylactate ester).	Effective in remediating VOCs in anaerobic conditions. May not be effective at well W-404 due to reportedly high dissolved oxygen (DO >4 mg/L).	• If effective, shorter time to achieve remediation goals. • No water discharge.	• Reductive dehalogenation is not feasible in extremely oxidizing conditions. • High intensity, short term disruption in well W-404 area. • No hydraulic capture / control of plume.
Ex situ Reductive Dehalogenation	Sulfur modified iron (SMI) is placed in a column equipped with a system to distribute the ground water containing VOCs evenly over the SMI bed. SMI is a granular media, consisting of porous iron particles mixed and wetted with sulfur. Sulfur reportedly increases reactivity of porous iron particles. Removal of chlorinated solvents occurs via step-wise reductive dehalogenation. This reaction results in the removal of chlorine atoms from the VOC molecule, and produces chloride ions and innocuous by-products including ethene. Once the SMI becomes oxidized, it is exchanged with new SMI and sent offsite for regeneration.	Some reported effectiveness in reducing VOCs, however field data are not conclusive.	• Chromium reduction.	• Not a proven technology. • Needs pilot or field scale tests. • Requires regular SMI change-out. • Treatment duration may be 15 years to achieve cleanup goals. • Requires construction of a treatment facility in Big Trees Park.
In situ Reductive Dehalogenation	Zero Valent Iron (ZVI) is added to the subsurface in slurried form as an abiotic electron donor to promote the reductive dehalogenation of the chlorinated VOCs. This reaction results in the corrosion (rusting) of the iron particles, removal of chlorine atoms from the VOC molecule, and produces chloride ions and innocuous by-products including ethene. The ZVI (Fe0) is oxidized to ferrous (Fe^{2+}) and then ferric (Fe^{3+}) iron in the ground water, and is then typically precipitated as iron hydroxide and ultimately forms iron oxide (Fe_2O_3).	Some reported effectiveness in reducing VOCs, however field data are not conclusive.	• If successful, shorter time to achieve remediation goals. • Chromium reduction. • No water discharge.	• Not a proven technology at LLNL. • High intensity, short term disruption at well W-404. • No hydraulic capture /control of plume.

Table 2. Concept Design Summary for Treatment Alternatives, TFA West Area, Lawrence Livermore National Laboratory, Livermore, California.

Title	Alternative 1 Plumbing Improvements to Connect well W-404 to the Arroyo Pipeline for Treatment at TFA	Alternative 2 Install New GAC and Ion Exchange Treatment System for Ground Water Extracted from well W-404	Alternative 3 Install a Sulfur Modified Iron (SMI) Treatment System to Treat Ground Water Extracted from well W-404	Alternative 4 Injection of Zero Valent Iron (ZVI) Slurry to Enhance Reductive Chlorination at well W-404 While Pumping at well W-109
Description	Install a pipeline to connect well W-404 to the existing Arroyo Pipeline.	Install a GAC system to remove VOCs and an ion exchange system at well W-404 to remove Cr^{6+} from ground water extracted from well W-404.	Install an aboveground SMI system to utilize enhanced reduction to remove VOCs and Cr^{6+} from ground water extracted from well W-404.	Inject ZVI, such as FeroxSM Microscale ZVI, into HSU 2 as an abiotic electron donor to promote the reductive dechlorination of PCE.
Design Basis	• 35 gallon per minute (gpm) treatment volume with total VOCs at 30 micrograms per liter (ug/L) and Cr6+ at 20 ug/L. • Arroyo Pipeline is Schedule 40 polyvinyl chloride (PVC) rated at 150 pounds per square inch (psi) • Terminal pressure is 5 psi at TFA. • Total flow to TFA from the Arroyo Pipeline is 156 gpm. • TFA will accommodate additional flow.	• 35 gpm treatment volume with total VOCs at 30 ug/L and Cr6+ at 20 ug/L. • Ion-exchange resin will not be regenerated onsite, but will require periodic replacement.	• 35 gpm treatment volume with total VOCs at 30 ug/L and Cr6+ at 20 ug/L.	• 25 ug/L PCE plume area of 125 feet (ft) by 125 ft. • Treatment is estimated to extend from 148 ft below ground surface (bgs) to 158 ft bgs. • Iron-to-soil mass ratio of 0.004.
Implementation	The proposed pipeline would be approximately 1,300 ft of double-walled pipeline (2-in. inner diameter / 4-in. outer diameter) that runs beneath the public footpath along Arroyo Seco (Alternative 1a) or in public right of way via Charlotte Way / Susan Lane (Alternative 1b). Routing will be based on existing utilities and easements. Supervisory control and data acquisition (SCADA) would be provided at TFA. A new pump would be installed at well W-404 capable of delivering 35 gpm at 350 ft head. New pumps may be installed at wells W-408 and W-903 if existing pumps are unable to overcome increased pressure in the Arroyo Pipeline. Landscaping and trail improvements may be required. Approvals are likely required from City of Livermore, and possibly U.S. Army Corps of Engineers and Zone 7 Water Agency.	A new security and sound attenuation structure approximately 13 ft wide x 16 ft long x 10 ft high would be built in Big Trees Park just southwest of where the Arroyo Seco crosses Charlotte Way. The system would include particulate filters, two in-series GAC units, two in-series ion exchange units, appropriate sample ports, effluent flow and pressure metering. Control would be accomplished with a programmable logical controller (PLC) and SCADA. The treated ground water would be discharged to a storm drain along Charlotte Way or directly to Arroyo Seco. The GAC units would be approximately 4 ft diameter and 8 ft 8 inches tall with 2,000 pounds (lbs) virgin GAC. Approximately three 2,000-lb carbon exchanges would be required each year. The ion-exchange units would be strong base anion (Type 1 / II), 2.5 ft diameter, 6 ft high, with 14 cubic foot resin capacity. Resin would be disposed/regenerated offsite. Approvals are likely required from City of Livermore, California Regional Water Quality Control Board and possibly U.S. Army Corps of Engineers and Zone 7 Water Agency.	A new security and sound attenuation structure approximately 15 ft wide x 20 ft long x 14 ft high would be built in Big Trees Park just southwest of where Arroyo Seco crosses Charlotte Way. The system would include particulate filters, SMI reactor (column), appropriate sample ports, effluent flow and pressure metering. Control would be accomplished with PLC and SCADA. The treated ground water would be discharged to a storm drain along Charlotte Way or directly to Arroyo Seco. The reactive media in the column will be SMI bounded by sand layers of approximately 6-inch thickness at the base and the top of column. The column would be 11 ft long and 8 ft diameter to effect a contact time of 60 minutes. Approvals are likely required from City of Livermore, California Regional Water Quality Control Board and possibly U.S. Army Corps of Engineers and Zone 7 Water Agency.	Using sonic drilling techniques, a pressurized water column will advance a 4-in casing to the target injection depth in each hole. Once at depth, atomized ZVI is injected as a slurry consisting of potable water and ZVI powder fed into a high flow, high-velocity nitrogen gas applied to the formation as the casing is retracted from the hole. Approximately 72,000 pounds of ZVI will be delivered into 17 boreholes, spaced approximately 35 ft apart within the treatment area. It is estimated that an effective radius of influence of 20 ft can be achieved. Estimated duration of injections: 20-26 work days. Two new HSU 2 monitoring wells (4-inch) are proposed: one within the treatment area and one downgradient of the 25 ug/L PCE plume. Approvals are likely required from City of Livermore and Zone 7 Water Agency, and possibly U.S. Army Corps of Engineers.
Uncertainties and Risks	Precise easement and utility locations. Existing condition of Arroyo Pipeline.	Availability/suitability of land at Big Trees Park.	Availability/suitability of land at Big Trees Park. Effectiveness not fully demonstrated.	The full area of the 25 ug/L PCE plume may not be accessible for injection. Significant disruption to neighborhood.

Table 4. Comparative Evaluation of Cleanup Alternatives, TFA West Area, Lawrence Livermore National Laboratory, Livermore, California.

Alternative	Threshold Criteria		Balancing Criteria					Modifying Criteria
	Overall Protection of Human Health and the Environment	**Compliance with ARARs**	**Long-Term Effectiveness**	**Reduction in Contaminant Toxicity, Mobility, and Volume**	**Short-Term Effectiveness**	**Implementibility**	**Cost**	**State and Community Acceptance**
Alternative 1 Plumbing Improvements to Connect well W-404 to the TFA Arroyo Seco Pipeline.	Yes. Protects human health and the environment due to active remediation at TFA.	Yes. Complies with ARARs.	Yes. Effective, reliable and reduces long term risk.	Yes. Contaminant mass, volume and mobility reduced by removing contaminants from ground water.	Yes. Some short term risk to the public exists during construction. Underground pipeline would be laid in easements though public areas.	Yes. Equipment and construction techniques are readily available. Approvals for work in multiple easements are required and obtainable.	Capital: $480,000 Annual: $8,000 15-yr Present Value Life Cycle Cost: $560,000	To be determined.
Alternative 2 Install New GAC and Ion Exchange Treatment System at well W-404 to Treat Extracted Ground Water.	Yes. Protects human health and the environment due to active remediation with new GAC and ion exchange system.	Yes. Complies with ARARs.	Yes. Effective, reliable and reduces long term risk.	Yes. Contaminant mass, volume and mobility reduced by removing contaminants from ground water.	Yes. Some short term risk to the public exists during construction. A permanent structure would be erected in Big Trees Park.	Yes. Equipment and construction techniques are readily available.	Capital: $510,000 Annual: $57,000 15-yr Present Value Life Cycle Cost: $1,100,000	To be determined.
Alternative 3 Install an SMI Treatment System at well W-404 to Treat Extracted Ground Water.	Yes. Protects human health and the environment due to active remediation by SMI.	Yes. Complies with ARARs.	Maybe. Emerging technology. Effectiveness and reliability are not fully demonstrated. Bench and field scale testing required.	Yes. Contaminant mass, volume and mobility reduced by destroying contaminants in extracted ground water.	Yes. Some short term risk to the public exists during construction. A permanent structure would be erected in Big Trees Park.	No. The price and availability of SMI are uncertain. The reliability of the technology is not fully demonstrated.	Capital: $720,000 Annual: $230,000 15-yr Present Value Life Cycle Cost: $3,100,000	To be determined.
Alternative 4 Injection of ZVI Slurry to Enhance Reductive Chlorination at well W-404 while pumping at well W-109.	Yes. Protects human health and the environment due to active remediation by ZVI in the subsurface.	Maybe. ESD may be required because injection to HSU-2 was not considered in ROD.	Maybe. Emerging technology. Effectiveness and reliability are not fully demonstrated for low concentration VOCs in deep HSUs. Bench and field scale testing required.	Maybe. Contaminant mass, volume and mobility reduced by destroying contaminants *in situ.*	Maybe. Significant short term disruption to the public during construction.	Maybe. Equipment and construction techniques are readily available. However, existing structures may not permit effective application of the technology.	Capital: $1,250,000 Annual: $4,000 15-yr Present Value Life Cycle Cost: $1,300,000	To be determined.

Table 5. Preliminary NEPA Review of the Concept Design Summary for Treatment Alternatives, TFA West Area, Lawrence Livermore National Laboratory, Livermore, California.

NEPA Impact Category	Alternative 1 Plumbing Improvements to Connect well W-404 to the Arroyo Pipeline for Treatment at TFA	Alternative 2 Install New GAC and Ion Exchange Treatment System for Ground Water Extracted from well W-404	Alternative 3 Install an SMI Treatment System to Treat Ground Water Extracted from well W-404	Alternative 4 Injection of ZVI Slurry to Enhance Reductive Chlorination at well W-404 While Pumping at well W-109
Land Use	Impacts are expected to be small because trenching for Christy boxes, electrical utilities connection (existing), and 1,300 feet (ft) of subsurface pipe would be in previously disturbed or landscaped areas, such as roadways, sidewalks, or footpaths. Repaving, sidewalk and footpath repair, and any impacted landscaping, would be replaced.	Impacts are expected to be moderate due to construction of the treatment system structure, most likely in a public park, although trenching needed to pipe treated ground water to a storm drain or to Arroyo Seco would be in previously disturbed or landscaped areas. Repaving, sidewalk repair, and any impacted landscaping would be replaced. Land use would be restricted until remediation is complete (<20 years).	Impacts are expected to be moderate because construction of the treatment system structure, most likely in a public park, although trenching needed to pipe treated ground water to storm drain or to Arroyo would be in previously disturbed or landscaped areas. Repaving, sidewalk repair, and any impacted landscaping would be replaced. Land use would be restricted until remediation is complete (<20 years).	Impacts would be moderate, although short term, because drilling of boreholes for injection of ZVI and 2 new monitor wells would occur over an approximately 1/3 acre area. Borehole locations would be in publicly accessible areas (surrounding community pool). Land use would be restricted indefinitely because boreholes, though grouted and capped, would remain in place.
Ecology	Impacts are expected to be small because trenching for Christy boxes, electrical utilities connection (existing), and 1,300 ft of subsurface pipe would be in previously disturbed or landscaped areas, such as roadways, sidewalks, or footpaths. Work would be designed and scheduled to avoid impacts to sensitive species. Concurrence required from DOE Livermore Site Office (LSO) for measures designed to avoid impacts to the California red-legged frog. Consultation with US Fish and Wildlife Service not likely needed, but may be recommended by LSO prior to beginning ground-disturbing activities and year-round water release to Arroyo Seco.	Impacts are expected to be small because construction of the treatment system structure, and trenching needed to pipe treated ground water to storm drain or to Arroyo Seco, would be in previously disturbed or landscaped areas, and impacted landscaping would be replaced. Work would be designed and scheduled to avoid impacts to sensitive species. Concurrence required from DOE LSO for measures designed to avoid impacts to the California red-legged frog. Consultation with US Fish and Wildlife Service not likely needed, but may be recommended by LSO prior to beginning ground-disturbing activities and year-round water release to Arroyo Seco. Notification of Alameda County Vector Control regarding new water release in this area required.	Impacts are expected to be small because construction of the treatment system structure, and trenching needed to pipe treated ground water to storm drain or to Arroyo Seco would be in previously disturbed or landscaped areas, and impacted landscaping would be replaced. Work would be designed and scheduled to avoid impacts to sensitive species. Concurrence required from DOE LSO for measures designed to avoid impacts to the California red-legged frog. Consultation with US Fish and Wildlife Service not likely needed, but may be recommended by LSO prior to beginning ground disturbing activities and year-round water release to Arroyo Seco. Notification of Alameda County Vector Control regarding new water release in this area required.	Impacts are expected to be moderate because trimming and removal of several trees, and the drilling of boreholes for injection of ZVI and 2 new monitor wells would occur over an approximately 1/3 acre area, including areas surrounding a community pool and on the bank of the Arroyo Seco. However, the work would be occurring in previously disturbed or landscaped areas and impacted landscaping would be replaced. Concurrence required from the LSO for measures designed to avoid impacts to the California red-legged frog. Consultation with US Fish and Wildlife Service may be recommended by LSO prior to beginning ground disturbing adjacent to Arroyo.
Water Use and Quality	Impacts are expected to be beneficial because ground water would be piped to existing Treatment Facility A (TFA) at LLNL and treated prior to discharge under existing NPDES permit. Remediation would result in improved ground water quality.	Impacts are expected to be beneficial because ground water would be treated prior to discharge under an NPDES permit. Remediation would result in improved ground water quality.	Impacts are expected to be beneficial because ground water would be treated prior to discharge under an NPDES permit. Remediation would result in improved ground water quality.	Impacts are expected to be beneficial because ground water would be remediated with injection of ZVI resulting in improved ground water quality.
Air Quality (Transportation)	Criteria emissions and greenhouse gas (GHG) emissions would occur with the operation of excavation, construction, and maintenance equipment, as well as transportation necessary to obtain, tools, materials and equipment required for the project. Impacts are expected to be small.	Criteria emissions and GHG emissions would occur with the operation of excavation, construction, and maintenance equipment, as well as transportation necessary to obtain, tools, materials and equipment required for the project. Impacts are expected to be small.	Criteria emissions and GHG emissions would occur with the operation of excavation, construction, and maintenance equipment, as well as transportation necessary to obtain, tools, materials and equipment required for the project. Impacts are expected to be small.	Criteria emissions and GHG emissions would occur with the operation of drilling and maintenance equipment, as well as transportation necessary to obtain, tools, materials and equipment required for the project. Impacts are expected to be small.
Wastes	Impacts are expected to be small. Excavated soil from trenching would be characterized prior to reuse at the project site. Excavated soil that does not meet reuse criteria would be disposed at an approved landfill. Non-hazardous general construction wastes that cannot be recycled or reused would also be disposed at an approved landfill.	Impacts are expected to be small. Excavated soil from trenching would be characterized prior to reuse at the project site. Excavated soil that does not meet reuse criteria would be disposed at an approved landfill. Non-hazardous general construction wastes that cannot be recycled or reused would also be disposed at an approved landfill. Approximately 3 tons of non-hazardous wastes would be generated annually from GAC and resin exchange and disposed at an approved disposal location.	Impacts are expected to be small. Excavated soil from trenching would be characterized prior to reuse at the project site. Excavated soil that does not meet reuse criteria would be disposed at an approved landfill. Non-hazardous general construction wastes that cannot be recycled or reused would also be disposed at an approved landfill. Approximately 15 tons of non-hazardous wastes would be generated annually from the reactive media exchange and disposed at an approved disposal location.	Impacts are expected to be small. Excavated soil from drilling would be characterized prior to reuse at the project site. Excavated soil that does not meet reuse criteria would be disposed at an approved landfill. Non-hazardous general construction wastes that cannot be recycle or reused would also be disposed at an approved landfill.

Table 5. Preliminary NEPA Review of the Concept Design Summary for Treatment Alternatives, TFA West Area, Lawrence Livermore National Laboratory, Livermore, California (continued).

NEPA Impact Category	Alternative 1 Plumbing Improvements to Connect well W-404 to the Arroyo Pipeline for Treatment at TFA	Alternative 2 Install New GAC and Ion Exchange Treatment System for Ground Water Extracted from well W-404	Alternative 3 Install an SMI Treatment System to Treat Ground Water Extracted from well W-404	Alternative 4 Injection of ZVI Slurry to Enhance Reductive Chlorination at well W-404 While Pumping at well W-109
Aesthetics	Impacts are expected to be small because new piping would be placed below ground. Repaving, sidewalk and footpath repair, and any landscaping would be repaired or replaced.	Impacts are expected to be moderate due to tree removal, tree trimming, and grading for placement of the treatment structure that would remain in place until remediation is complete (<20 years). However, new piping would be installed below ground and impacted landscaping would be replaced.	Impacts are expected to be moderate due to the placement of the treatment structure, most likely in a pubic park, that would remain in place until remediation is complete (<20 years). However, new piping would be installed below ground and impacted landscaping would be replaced.	Impacts would be moderate to large, although short term, because removal of trees, and the drilling of boreholes for injection of ZVI and 2 new monitoring wells would occur over an approximately 1/3 acre area, in publicly accessible areas and on bank of Arroyo. Boreholes would remain in place, but would be not be visible upon completion of project.